Quantifying Turbulence in the Coastal Environment

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LONG-TERM GOAL

Enhanced understanding and models of stratified turbulence and small-scale coherent structures, leading to improved predictions of conditions in coastal marine environments.

OBJECTIVES

- Develop a new methodology for measuring stratified turbulence and coherent structures in coastal environments.

- Obtain turbulence measurements sufficient for a critical evaluation of turbulence closure models and large eddy simulations in stratified flows under a wide range of conditions.

- Quantify the interactions of turbulence, sub-mesoscale and mesoscale motions in estuarine environments.

APPROACH

The approach is shipboard deployment in an estuarine setting of the Mobile Array for Sensing Turbulence (MAST), a shipboard system designed to obtain high-resolution measurements of velocity, temperature and salinity throughout the top 7.5 m of the water column (Figure 1). The MAST was constructed during 2005 at the Woods Hole Oceanographic Institution (WHOI) with funding from the Defense University Research Instrumentation Program (DURIP). The system consists of a 12-m aluminum cylinder, deployed nearly vertically, which is attached to a cross-member near the bow of a coastal research vessel. The cylinder is instrumented with an array of co-located and coherently sampled acoustic Doppler velocimeters and fast-response microstructure conductivity and temperature sensors. The system is designed to produce direct measurements of the vertical shear and stratification; direct-covariance estimates of the turbulent fluxes of momentum, buoyancy and turbulent kinetic energy; and inertial-range estimates of the dissipation rates for kinetic energy and scalar variance.

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WORK COMPLETED

During July 2006, the MAST was deployed in the Snohomish River estuary in Puget Sound. The MAST measurements were carried out in conjunction with an ONR-funded Multidisciplinary Research Initiative (MURI), entitled Coherent Structures Experiment (COHSTREX), which is being conducted by Andy Jessup, Alex Horner-Devine and Bill Plant, of the University of Washington, together with Steve Monismith, Robert Street and Derek Fong, of Stanford University. The purpose of the MURI is to understand the dynamics of coherent structures which are visible in estuaries in remotely sensed images of the sea surface. The Snohomish estuary is a few meters deep, subject to tidal currents that often exceed 1 m/s, and characterized by stratification that varies from slightly unstable to strongly stable during each tidal cycle. The MAST measurements in the Snohomish estuary were divided approximately equally between two purposes: (1) quantifying stratified boundary layer turbulence under approximately horizontally uniform conditions in a nearly prismatic section of the channel, and (2) determining the subsurface signatures of coherent structures, including convergence fronts and eddies shed by submarine topography, in support of the MURI activities.

Figure 1. Top panel: photograph of the MAST in its transit (up) position on the WHOI research vessel Tioga during a test deployment near Woods Hole. Bottom left panel: close-up photograph of one of six sets of co-located sensors, including an acoustic Doppler velocimeter (ADV), a conductivity-temperature-depth (CTD) sensor, and a fast-response conductivity sensor. Bottom right panel: photograph of the MAST in its measurement (down) position on the UW research vessel Centennial during the July 2006 COHSTREX program in the Snohomish River estuary.

RESULTS

MAST measurements in a nearly prismatic section of the Snohomish estuary have produced the first (to our knowledge) simultaneous, co-located field measurements of shear, stratification, Reynolds stress, buoyancy flux, and dissipation throughout a large fraction of the water column under energetic forcing in a stratified turbulent flow. Typical results during ebbing tide with stable stratification (Figure 2) include a downward transport $\rho_0\langle uw\rangle$ of streamwise momentum and an upward transport

<bw> of buoyancy anomaly $b = (g/\rho0)\rho'$, where $\rho0$ is the reference density, u and w are the streamwise and vertical velocity fluctuations, g is gravitational acceleration, and ρ' is the density fluctuation. The stress $\rho0$<uw> increases nearly linearly with distance z below the surface, as expected in a shallow, strongly forced turbulent flow, and the cospectra have a shape characteristic of boundary layer turbulence and indicate a dominant flux-carrying scale limited by the distance to the boundary. Corresponding results during flooding tide (Figure 3) indicate a downward buoyancy flux associated with advection of salty water over fresher water by the sheared tidal current, a process which has been hypothesized but not previously observed directly.

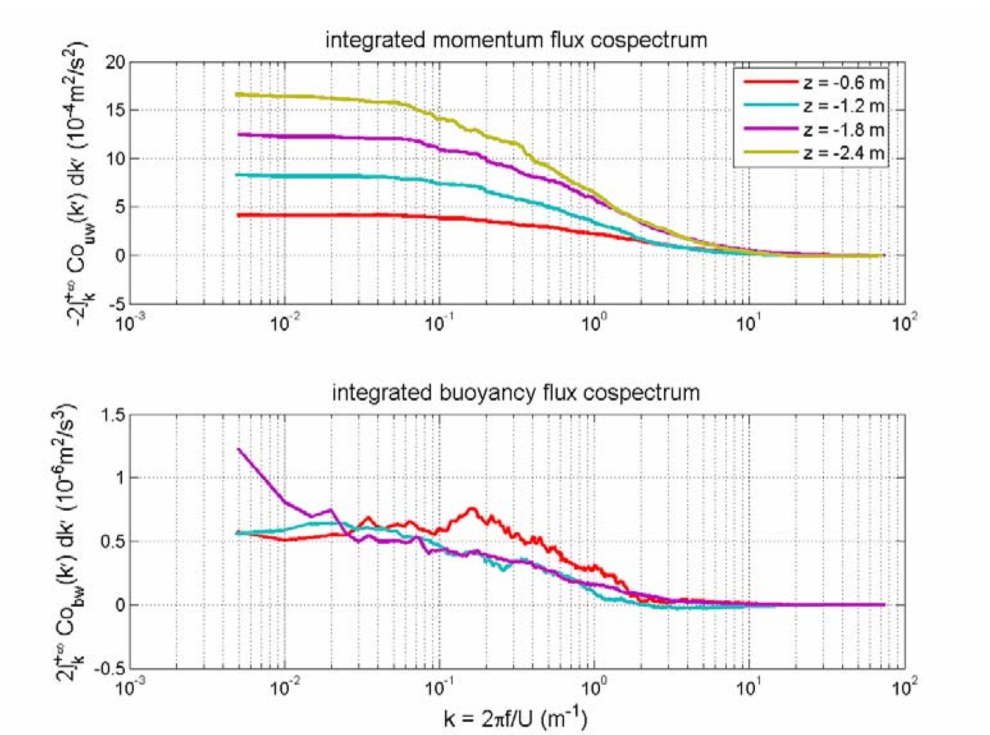

Figure 2. Cumulative integrals of cospectra of streamwise velocity u and vertical velocity w (top panel) and buoyancy anomaly $b = (g/\rho0)\rho'$ and vertical velocity w (bottom panel) during ebbing tide. The momentum flux <uw> and buoyancy flux <bw> can be read as the limit of the integrals as the wavenumber k approaches zero (excluding anomalous low-wavenumber behavior associated with ship motions and other low-frequency fluctuations). The cospectra indicate a characteristic flux-carrying turbulent scale (determined by the inflection points in the integrated cospectra) of approximately 1 m.

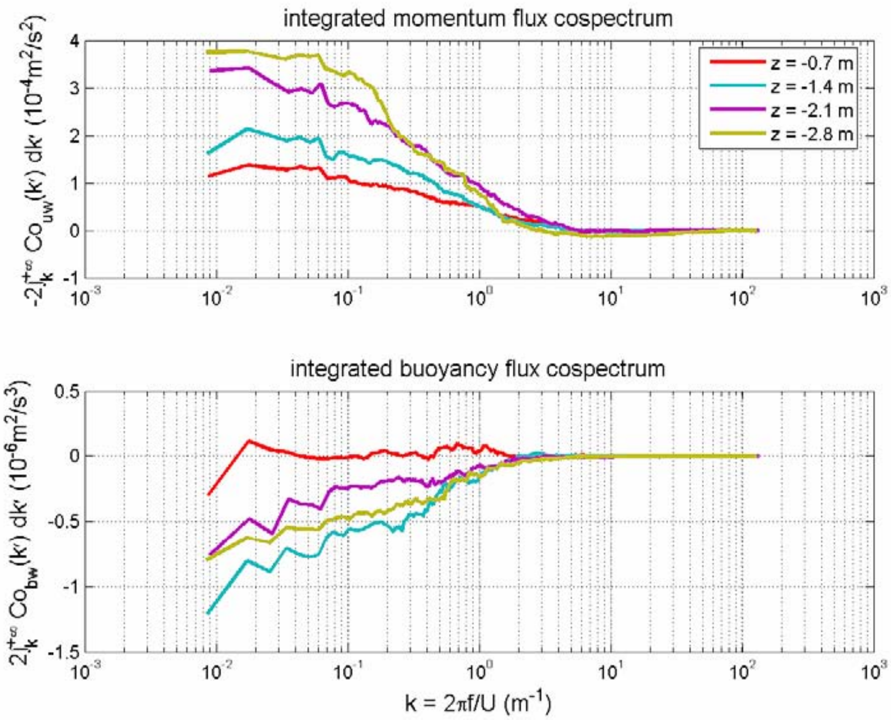

Figure 3. Cumulative integrals of cospectra of streamwise velocity u and vertical velocity w (top panel) and buoyancy anomaly b = (g/ρ0)ρ' and vertical velocity w (bottom panel) during flooding tide. The interpretation is as in Figure 2. Note that the buoyancy flux <bw> is negative, indicating downward transport of dense water, a process that has been hypothesized but not previously measured directly in an estuarine setting.

MAST observations in support of the MURI operations were carried out within the field of view of remote sensing instrumentation deployed by the MURI researchers. These measurements were carried out in a field of surface-impacting eddies shed by a submerged shoal and in an along-channel convergence front.